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"FIREARMS IDENTIFICATION USING PATTERN ANALYSIS AND COMPUTATIONAL MODELING"

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This paper describes a computational approach to the analysis of firearms forensic images, in particular, bullet images. Expended bullets usually bear characteristic surface markings associated with the mechanisms of the firearm that fired them. The traditional method of comparing bullet and cartridge markings involves the labor-intensive process of visual identification through a comparison microscope. This project proposes that the same process can be duplicated, and accelerated, using a low-cost video imaging and image processing system. The deevelopment of this project requires three important phases - "collection", "processing", and "analysis". In a laboratory scenario, the "barcodes" of the crime bullet and test bullet images are matched against each other. The barcode of the crime bullet is also matched against the barcodes of other potentially similar bullet images from the image database. A probability of match is generated for each comparison, and bullet images with a low probability of match are ignored. This effectively reduces the firearms examiner's workload. The bullet images with a high probability of match are retrieved, and displayed simultaneously to confirm the match.

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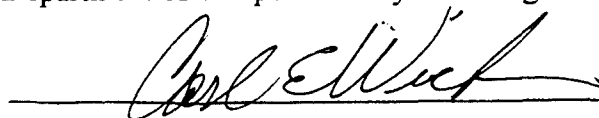
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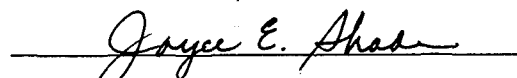
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ABSTRACT

This paper describes a computational approach to the analysis of firearms forensic images, in particular, bullet images. Expended bullets usually bear characteristic surface markings associated with the mechanisms of the firearm that fired them. These markings are of special importance to the firearms examiner, because they are unique to a particular firearm, similar to the distinctive nature of human fingerprints. The traditional method of comparing bullet and cartridge markings involves the labor-intensive process of visual identification through a comparison microscope. This project proposes that the same process can be duplicated, and accelerated, using a low-cost video imaging and image processing system.

The development of this project requires three important phases - "collection", "processing" and "analysis". In the first phase, "collection" involves obtaining the appropriate bullet samples for image capture to create a preliminary image database for experimental work. The United States Bureau of Alcohol, Tobacco and Firearms (USBATF) provided eight laboratory-standard bullets for this project.

The second phase, or "processing" phase, features the use of various image processing techniques to enhance the

image for analysis. When a bullet is fired, it travels through the barrel along deep spiraling grooves, known as "rifling", found on the inner surface of the barrel. This imparts a spin on the bullet, enabling it to travel on a straight plane. The abrasive contact between the bullet and groove surfaces produces "lands" on the bullet surface. Each "land" contains the characteristic bullet markings, which tend to be linear in nature. Hence, the main goal is to discover these markings, which resemble straight lines, and use them for bullet identification.

There are many image processing techniques that specialize in the enhancement of linear features. In this project, three of the more well-known edge detection filters were used. They were the Sobel, Roberts, and Prewitt filters. After some detailed experimentation with the four filters, the Sobel filter was found to be the optimum filter for detecting the bullet markings.

Finally, in "analysis", a small area of the enhanced bullet image that encloses a "land" is interpreted, and useful data that is critical to bullet identification are extracted. This data includes the frequency, width, and orientation of the bullet markings. In order to perform data extraction, a simple algorithm was designed to interpret lines on the bullet images, and record the location and angle of each marking. Once the bullet data is derived, the data is

translated into "bar-codes" to speed up the bullet matching process. A match is obtained faster using these "bar-codes", because they contain less data and noise.

In a laboratory scenario, the "bar-codes" of the crime bullet and test bullet images are matched against each other. The "bar-code" of the crime bullet is also matched against the "bar-codes" of other potentially similar bullet images from the image database. A probability of match is generated for each comparison, and bullet images with a low probability of match are ignored. This effectively reduces the firearms examiner's workload. The bullet images with a high probability of match are retrieved, and displayed simultaneously to confirm the match.

ACKNOWLEDGEMENTS

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SECTION 1 - INTRODUCTION

1.1 BACKGROUND

Violent crime is a great concern for many Americans. There were 24 percent more violent crimes in 1992 than in 1973. In 1992, 24 percent of all American households were affected by crime, violent or otherwise. Unfortunately, children are also increasingly involved in violent crime. Between 1979 and 1991, the firearm homicide rate among black men aged 15 to 19 nearly quadrupled; among the white men of the same age group, there was a 73 percent increase.[1]

In many of the violent crime cases, the offenders are not apprehended at the scene of crime. Bullets, cartridge casings, and weapons, are some of the items commonly recovered by the forensic experts at the crime scene. The forensic experts use these items to reconstruct the crime, producing sufficient evidence in court to convict the perpetrators of the crime. There are many important areas in forensic science, such as, firearms identification, fingerprint matching, and DNA-matching. Firearms identification, specifically bullet identification, is used to determine the source of the crime bullet. Once the crime bullet is linked to a particular weapon, the question of guilt is resolved. Next, the arrest and conviction of the

weapon's user is made.

Bullet identification has a long history. During the days of the Roman Empire, the cast lead bullets thrown by slingers in the Roman legions had individual legion emblems upon them. English archers of the Fourteenth Century frequently marked their arrows distinctively. Hence a particular fatal pellet or arrow could be traced to a certain unit.

Knowledge of firearms identification was possessed only by a few individuals before the end of the Nineteenth Century. It was largely personal, and there was no interchange of ideas through publications and societies. Scientific literature on the subject did not exist.

However, in June 1900, an article written by Dr. Albert Llewellyn Hall was published in The Buffalo Medical Journal, and it made a significant impact on the world of forensic science.[2] Dr. Hall had found time during his medical practice to do research on bullet wounds. The discoveries he made still form some of the basic principles of bullet identification today.

In recent years, crimes solved by firearms evidence are becoming more common. However, in forensic science, the advantages of modern technology are not fully exploited, and there is a tremendous potential for progress in this field. The accelerated growth of gun-related crimes, coupled with

the ever increasing number of handguns manufactured and distributed, make the improvement of firearms identification an urgent and important task.

The firearms expert is involved in many gun-related police investigations. The expert's testimony on any firearms evidence recovered from the crime scene is admissible in court. As a result, in a case where firearms evidence constitutes the only evidence available, it is still possible to convict the suspect.

The trend in firearms identification is towards simplicity and efficiency. The expert is primarily concerned with matching crime bullets with test bullets from suspect weapons, rather than forecasting what type, make and model of weapon will ultimately be proved to have fired the crime bullets.[3] When a crime bullet is recovered from a victim or from the scene of the crime, the police may apprehend several likely suspects linked with the crime, who are frequently found carrying weapons with them. These recovered weapons are sent to the firearms laboratory. Test bullets from each weapon are compared not only with the specific crime bullet, but every other bullet of a similar calibre on file.

In present-day laboratories, appropriate equipment is essential to the work of the firearms expert. Since the first laboratories were established during the 1930s, most of the equipment has not undergone major design modifications. The

following describes four important components of a modern laboratory.

First, a bullet recovery trap is required to stop bullets fired from suspect and crime weapons.[4] These bullets must not be deformed in order to be useful. One arrangement used by the United States Bureau of Alcohol, Tobacco and Firearms (USBATF) laboratory in Rockville, Maryland, is a six-foot by three-foot wide water tank. Bullets are fired at a small angle below the horizontal into the two-foot deep water. Since water is relatively incompressible, the high-velocity bullets experience tremendous water resistance, and are stopped after a short distance through the water. The bullets recovered by this method are almost always perfect for examination.

Second, a good weight scale is required, and must be capable of measuring small weights. This is used to give an accurate measurement of the weight class of the bullet, which is an important identification characteristic.

Third, a wide-field binocular microscope is needed for the examination of bullets and cartridge cases. This instrument gives a stereoscopic effect to the bullet specimen, which enables the determination of the depth of depressions and scratches on the surface of the bullet.

Fourth, and most important of all, is a comparison microscope. A comparison microscope consists of two

microscopes joined optically by a bridge so that one-half of the image seen through the bridge eye-piece shows one bullet and the other half, the other bullet. The pattern formed on the bullet is unique to a particular firearm, and the expert can determine a match by aligning and comparing both half-images.

The manual process of bullet identification requires a lot of time, energy, and training. Besides being labor-intensive and skill-intensive, the expert must also possess a good memory in order to keep track of as many active cases as possible. This helps to quickly determine if a particular bullet of interest is related to past shootings, without searching through the entire volume of active case files.

Many gun-related crimes committed in cities within a certain region can be traced to a particular person or gang. The traditional forensic laboratory has limited means of exchanging information with other laboratories. This severely impairs the ability of linking and solving crimes on a regional basis.

Although very infrequent, the expert is capable of human error. Each expert may have a different theory for bullet identification. This statement is, by no means, aimed to discredit the authority of the evidence provided by the firearms expert, but as a precautionary suggestion that perhaps an automated system may aid the expert in eliminating

all potential mistakes.

The staggering increase in gun-related crimes in recent years has overwhelmed law enforcement agencies and forensic laboratories supporting them. These laboratories are unable to handle the heavier workload, due to the small pool of qualified firearms experts. The result is a longer turnaround time, and more case backlogs.

What is crucial in all cases of firearms identification is the need for speed, accuracy and consistency. The computer offers a means of data storage and retrieval, image processing and analysis, and database network capabilities. Modern computer processor chips are able to efficiently process and handle large volumes of data. The computer can also repeat any assigned tasks in a consistent manner. It is not subject to human exhaustion, and can be utilized for a long time without any disruptions. Furthermore, when a network of computers is set up between two or more laboratories in a region, database information and bullet images can be shared freely, overcoming many jurisdictional, logistical, and chain-of-custody issues related to criminal evidence. Consequently, there must be a means to prevent unauthorized access into this network.

An efficient and reliable automated firearms identification system can potentially become an important tool in the forensic laboratory. However, the cost of

providing every laboratory with this computerized system of bullet identification could be of a major concern. This project makes the effective use of computer software in order to minimize hardware components, and thus reduces the overall cost of the system.

1.2 AIM

The aim of this project was to design a low-cost image processing system that was capable of aiding the firearms expert in the identification of bullets. The design involved both hardware and software components, as both were essential to the proper functioning of the system.

The system hardware is capable of producing high quality bullet images. Any section of the bullet surface can be captured by controlling the motor that turns the bullet attachment base. These images can be easily stored or retrieved for image processing. The software is written in Microsoft C/C++ for Windows 3.1, so that it resembles a professional software package, and provides a user-friendly environment. The image processing steps look for lines in the bullet images, and extracts the data relating to those lines. This data is then translated into a simple "bar-code". A "bar-code" system of bullet matching effectively cuts down the time required to scan through all the images in the database. The bullet images matching "bar-codes" are

retrieved, and carefully analyzed by the forensic expert to confirm the match.

SECTION 2 - THE PROBLEM OF FIREARMS IDENTIFICATION

Although firearms identification is only one aspect in forensic science, it requires many years of study, and much experience, in order to qualify as an expert. Two of the topics common to firearms identification are bullet identification, and cartridge case identification.

In bullet identification, the expert must be familiar with all existing types of bullets and their associated class characteristics, the elemental components of the bullet material, and the knowledge of projectile ballistics. Moreover, the expert must be able to differentiate between the various kinds of markings found on the surface of the bullet.

2.1   TYPES OF BULLETS

At present, lead bullets and jacketed bullets are the two basic types of commercial bullets in use.[5] Lead bullets are normally used in revolvers and in some low and medium powered rifles. A revolver is distinguished by a rotating ammunition barrel. Lead bullets are, in general, most frequently used in crime. Many lead bullets recovered from victims are fairly intact, and qualify as good candidates for microscopic comparison.

Jacketed bullets are more commonly found in pistols and high powered rifles. A pistol or a rifle uses a removable bullet clip, which is inserted into the clip housing prior to firing. Jacketed bullets found at crime scenes tend to belong to automatic pistols, automatic rifles and sometimes, sporting rifles. A full metal-jacketed rifle bullet that is fired, travels at a great velocity. It rarely stops in a human target, and is more likely to exit the victim and collide with a wall, floor or some other hard substance. The final collision tears the bullet into tiny pieces, hence, identification requires much effort to reconstruct the fragments and there may be a loss in evidence value.

2.2 THREE TYPES OF TASKS

There are three types of tasks associated with bullet identification.[6] First, given a bullet, determine the type and make of firearm from which it was fired. Second, given a bullet and a suspected firearm, determine whether or not the bullet was fired from the suspected firearm. Third, given two or more bullets, determine whether or not they were fired from the same weapon.

This project solves these three tasks using three levels of bullet identification. Level one identification involves the use of class characteristics for comparison, that is, the detailed physical description of the bullet(s) in question.

These class characteristics, or descriptors, include weight, diameter, length, twist of the rifling marks, pitch of the rifling, and angle of the rifling. The rifling in a weapon is a series of grooves cut into the surface of the barrel. These grooves cause the spinning of the bullet, providing projectile stability, and hence, the accuracy of the aim is increased. The spiral strips of the original barrel surface, left between the grooves, are called lands. These lands are responsible for making the characteristic rifling marks on the surface of the bullet. The twist of the rifling may be left-handed or right-handed. A left hand twist has rifling marks sloping to the left as they move away from the observer. Similarly, a right hand twist has rifling marks sloping to the right (Figure 1). The pitch of the rifling refers to the length of the rifling before it completes one turn. It is described as having one turn in so many inches or centimeters. The angle of the rifling is a measure of the gradient of the rifling in degrees.

Level two identification compares special markings, such as skid marks and stab marks. A skid mark is caused by the failure of the bullet to take up the rotation immediately when it strikes the rifling. A stab mark is a depression made on the surface of the bullet, which is used to hold the bullet in the neck of the cartridge case (Figure 2).
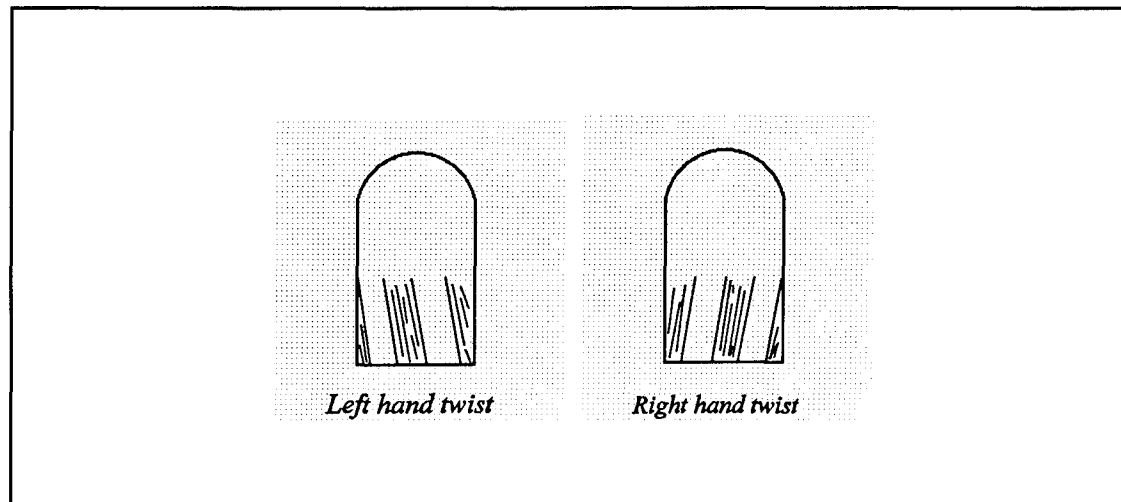
Figure 2
Bullets showing the twist of the rifling.

Figure 2
Bullet image showing skid marks and stab marks.

Level three identification utilizes the width, depth, inclination, and number of marks or striations on the lands of the bullet for analysis. This is the most time-consuming level of the three. A bullet's diameter is usually slightly larger than the diameter of the barrel. Therefore, when a bullet is fired, it is forced through the barrel, and

friction with the lands in the barrel creates characteristic marks on the lands of the bullet. These three levels need not be applied in sequential order, instead, they can be used simultaneously.

This project demonstrates that the computerization of level three identification is possible with a low-cost imaging and image processing system. Since depth measurement of the marks on the lands is useful, but not critical in bullet identification, the analysis of bullet images is restricted to two dimensions. Future undertakings of this project may incorporate three-dimensional surface mapping techniques to enhance the process of identification.

SECTION 3 - INTRODUCTION TO IMAGE PROCESSING

Image processing has a two-fold purpose. One, it is used to improve the visual appearance of images to please the human eye. Two, it prepares the images for measurement of the features or objects present. This project concentrates on the latter purpose.

Before an image can be measured, its features must be well defined, either by edges, or uniform color or brightness. The image processing steps to undertake depend largely on the type of measurement required. Many times, the best method is determined by actual experimentation. It is important to note that many image processing techniques either reduce the amount of data present, or rearrange it to convey more meaning.

3.1 WHAT IS AN IMAGE?

An image can be described as continuous or discrete. A continuous image, also known as an abstract image, is a function of a continuous variable, where each position in the image has some value. A discrete image is a function of a discrete variable, and it represents the abstract image. In order to obtain a discrete image, the abstract image must be digitized. During image digitization, the spatial coordinates

of the image are sampled, and the intensity of the image at each coordinate is translated into an integer value. This numerical representation of the image makes it suitable for digital processing in a computer.[7]
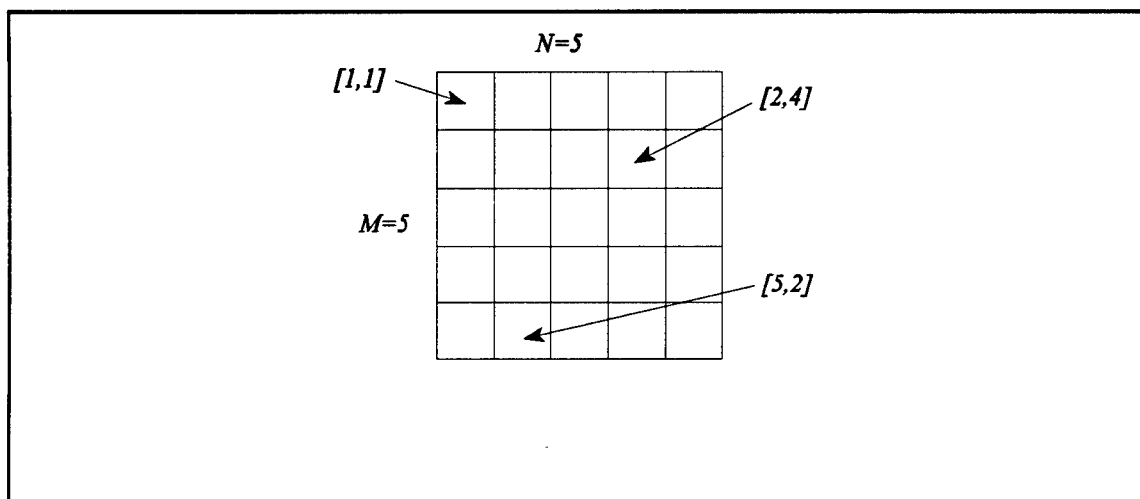
Figure 3
A 5x5 image matrix.

A two-dimensional discrete image is a function f(x,y), where x and y denote spatial coordinates and the value associated with f(x,y) describes a particular attribute of the image at that particular position. Examples of image attributes include brightness and color. An image can also be considered as an array or matrix, whose row and column indices [i,j] relate to the location of a point in the array (Figure 3), and the associated matrix element (or pixel) value is the grey scale value at that point. For example, in a 256-greyscale image, each pixel value, which is an integer, can range from 0 through 255, with 0 denoting a "black" pixel at one extreme of the uniform grey scale, and 255 indicating

a "white" pixel at the other end of the scale.

3.2 QUALITY OF IMAGES

The number of grey levels is directly related to the quality of the image. A 512-greyscale image generally appears to have greater detail and more features, compared to a similar image with only 16 grey levels. However, the more detailed image takes up a larger amount of computer memory during image processing, and uses a significant portion of hard disk space for storage.

An image array of size MxN has M rows and N columns. Accordingly, a 1024x768 Super VGA image will contain 786,432 pixels. Assuming that there are 2^8 (or 256), grey levels in the image, and each pixel value uses 8 bits (or 1 byte), of memory space, the image will require a total of 786,432 bytes. In contrast, a binary image of similar size with 2^1 grey levels (black or white), will only use up 98,304 (1024*768/8) storage bytes.

This project requires the use of high quality bullet images in order to extract the important linear features for identification. A 256-greyscale bullet image is found to contain sufficient detail for linear feature extraction. The images with 16 or 64 grey levels distort the important linear features, and the 512-greyscale images consume too much memory without providing any significant enhancement during

image processing. The image is also limited to 640x480 in size, which provided adequate resolution. As a result, each bullet image needs 307,200 bytes of memory.

3.3 IMAGE PROCESSING TECHNIQUES

Image processing is used to highlight or suppress certain features in an image. Some of the more important image processing techniques include geometric transformations, histogram techniques, spatial filters, and spatial frequency filters. Geometric transformations are concerned with the orientation, aspect ratio, and location of the image. They tend to leave the pixel values intact, dealing only with the spatial coordinates. In contrast, histogram techniques, spatial filters, and spatial frequency filters are used to change actual pixel values to give a desired visual effect.

3.4 GEOMETRIC TRANSFORMATIONS

Geometric transformations are used to translate, rotate, and scale the image.[8] Most of the transformations are reversible. Translation of an object in an image involves moving the entire object from the original position in the image to another location (Figure 4). This helps to align two bullet images from different locations, so that both images are next to each other, and can be simultaneously compared.
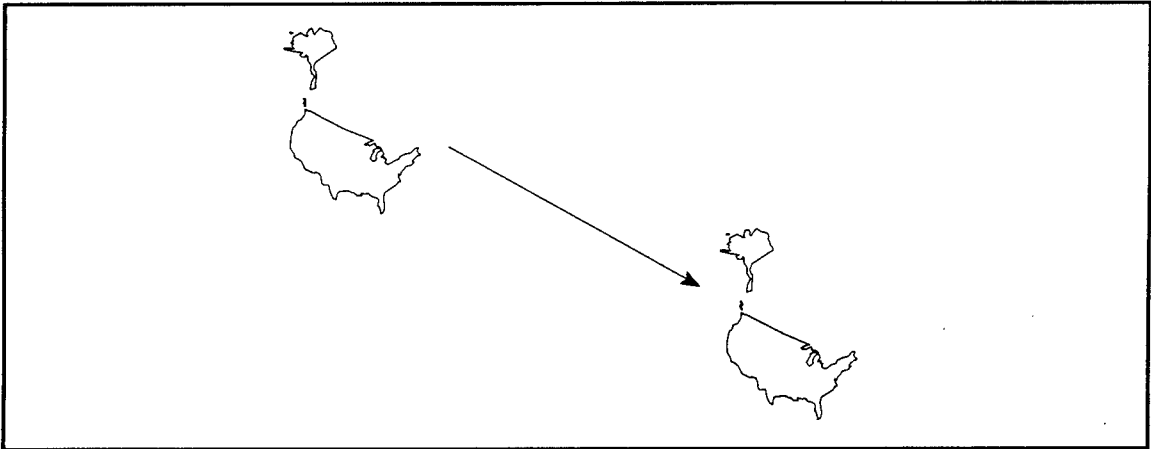
Figure 4
Translation of an object in an image.

Rotation of images usually occurs in 90-degree increments to preserve relative spatial coordinates. However, by using warping techniques, an image can be rotated at any given angle of rotation. The disadvantage associated with warping an image is that the relative spatial coordinates are often altered by rounding-off errors. This may cause some errors during the reverse process, when the image is returned to its original orientation.

The process of rotating an image in steps of 90° is simple. The row pixels of the original image is copied to the column pixels of the target image in the direction of rotation. This method is repeated for every 90° rotation of the image (Figure 4). Rotation is a useful tool, because it allows the reorientation of a poorly aligned bullet image.

Scaling (zooming or dezooming) is the process of increasing or decreasing the magnification of an image. A scale factor of 2, which is equivalent to a 200% increase in size, is achieved when each pixel in an image is reproduced four times (Figure 5). Therefore, a 256x256 image would become 512x512 in size. Zooming does not increase the amount of original image detail, instead, it allows the user to see the smaller objects in the image with greater clarity.
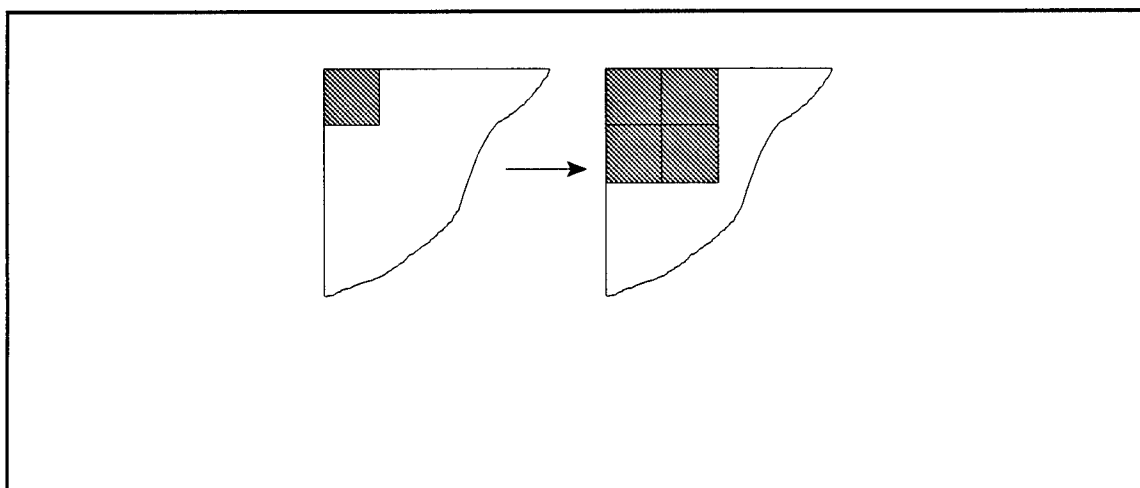
Figure 5
A pixel zoomed with a scale factor of 2.

3.5 HISTOGRAM TECHNIQUES

Histogram techniques comprise of histogram equalization and thresholding.[9] An image histogram is a set of numbers describing the percentage distribution of image pixels at the various grey levels. Consider a 512x512 image with 256 grey levels. The total number of pixels, N_t, is equal to 512*512 = 262,144. At each grey level from 0 to 255, there are N_i

number of pixels. Therefore, the percentage distribution of pixels, Di, at a particular grey level is equal to (Ni/Nt)*100. Consider the following example:

$$\text{Total number of pixels, } Nt = 512 \times 512 = 262,144 \qquad \textbf{(1)}$$

Grey levels	Ni	Di (%)
0	734	0.280
1	2754	1.051
2	3267	1.246
3	1245	0.475
4	2356	0.899
5	8354	3.187
6	4562	1.740
255	7343	2.801

Table 1
Values obtained from a histogram of the 512x512 image.

Equation (1) describes the total number of pixels that is used in the histogram calculation. A portion of the Ni and Di values obtained from the image is complied in Table 1. The plot of Di against the grey level values constitute an image histogram (Figure 6).

The aim of histogram equalization is to redistribute the grey level values of image pixels, so that the number of pixels in every grey level is about the same. The equalized image may appear to have more contrast and detail. However,

the equalization of bullet images seems to blur the linear features. Hence, the histogram techniques are not used in this project. See Figures 7 and 8 on the next page, for a comparison of the original bullet image and an equalized bullet image.
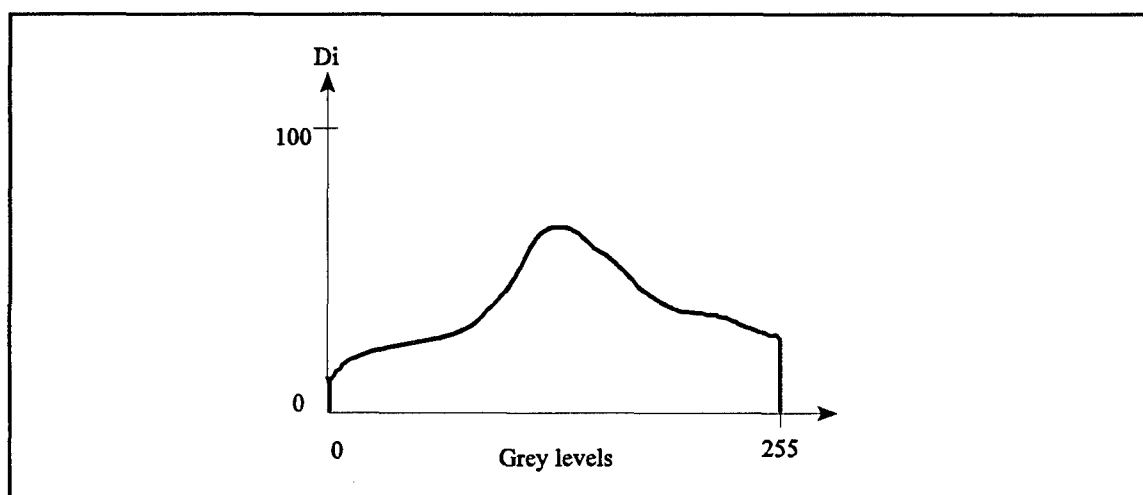
Figure 6
Histogram of the 512x512 image.
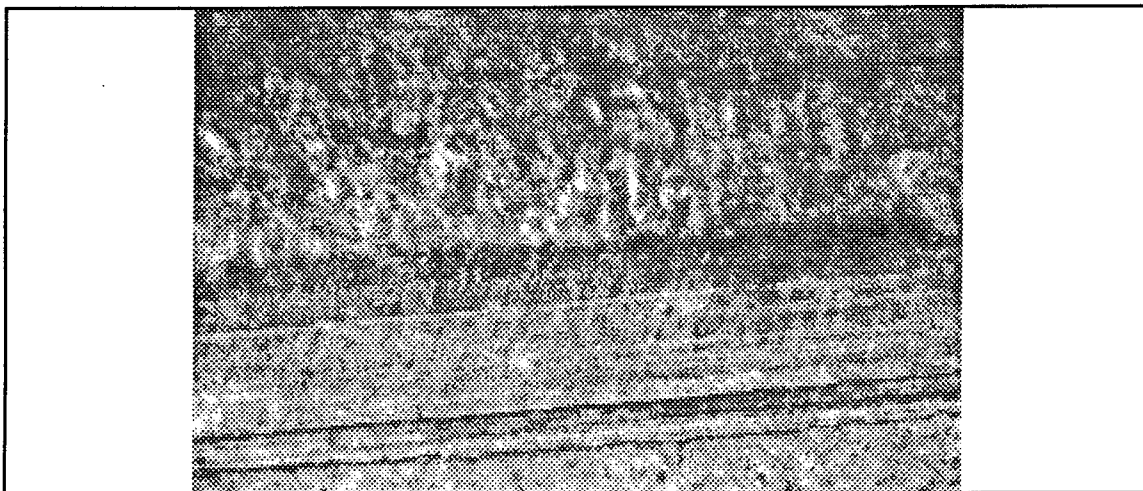
Figure 7
Original bullet image.

Figure 8
Equalized image. Notice that the regions appear darker and blurred.

3.6 SPATIAL FILTERS

Spatial filters, or discrete convolution filters, are algorithms that multiply a small image section, called a mask, with the target image.[10] They incorporate local, or neighborhood, operations on pixels. As the source filter is applied to each particular pixel in the target image,

calculation of the new value of that pixel is affected only by its neighboring pixels, and not pixels elsewhere. These new pixel values constitute the resultant image (Figure 9).

SOURCE FILTER
+
TARGET IMAGE

| CONVOLUTION

RESULTANT IMAGE
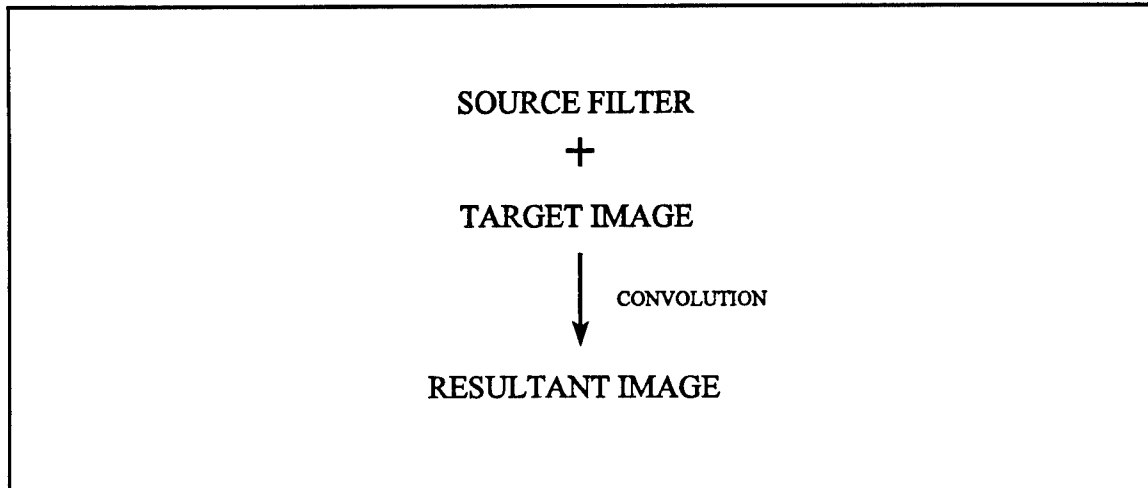
Figure 9
Overall process in convolution.

Spatial filters comprise of edge detection filters, and enhancement filters. Edge detection filters are used to find edges in an image. Examples of edge detection filters are the Roberts[11], Prewitt[12], and Sobel[13] filters. These filters are elaborated in the next section. Enhancement filters are used to reinforce important details in an image. They comprise of the mean, sharpening, and smoothing filters. The disadvantage of using enhancement filters is that, they are not selective in nature. In bullet images, they are capable of enhancing both important lines, and unwanted noise. Hence, these filters are not utilized prior to edge detection, because they tend to cause the detection of false lines.

3.7   SPATIAL FREQUENCY FILTERS

Spatial frequency filters manipulate all frequency components contained within an image.[14] The ability to modify an image's frequency components allows the user to remove periodic noise, enhance edges, and soften or sharpen the overall image. The discrete Fourier Transform (DFT) is used to decompose an image into a set of sine and cosine components, where the frequency and amplitude of each represent spatial frequencies within the image (Figure 10).

Original Image of Square   DFT of Square
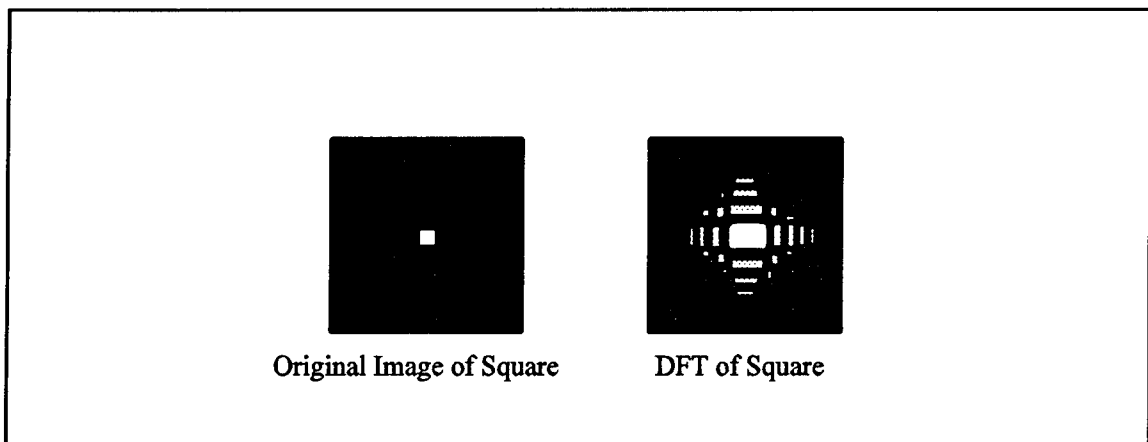
Figure 10
Discrete Fourier transform of a square.

If the high-frequency components of an image are reduced, the resulting image tends to be softened or blurred. However, when the high-frequency components are enhanced, the resulting image tends to be sharpened and its edges more defined.

The aim of this project is to detect linear features of bullet images. The application of spatial frequency filters

require a user-input, because the user has to decide which frequency components are to be removed. The decision-making varies for different images. Unlike spatial frequency filters, spatial filters are user-independent, and they perform similar functions. Therefore, this project concentrated on the use of spatial filters.

SECTION 4 - EDGE DETECTION FILTERS

Edge detection plays a crucial part in object recognition. An object's boundary is comprised of many edge segments. When the boundary of an object can be traced successfully, the process of shape analysis is greatly simplified. Edges need not necessarily reflect actual edges of an object, but they can correspond to shadows in an image (illumination discontinuity) or a surface mark (reflectance discontinuity). This project applies the classical mask method, which is based on convolution, to detect the lines or edges in the bullet images.

4.1 DEFINITION OF AN EDGE

In edge detection, the aim is to find intensity or color discontinuities because they are likely to occur at boundaries of objects. An ideal edge, when viewed in one dimension, is a step change in intensity.[15] However, in reality, most images are corrupted by noise from sensor, surface, or illumination variations. Thus, edge segments would also be mixed with noise (Figure 11).
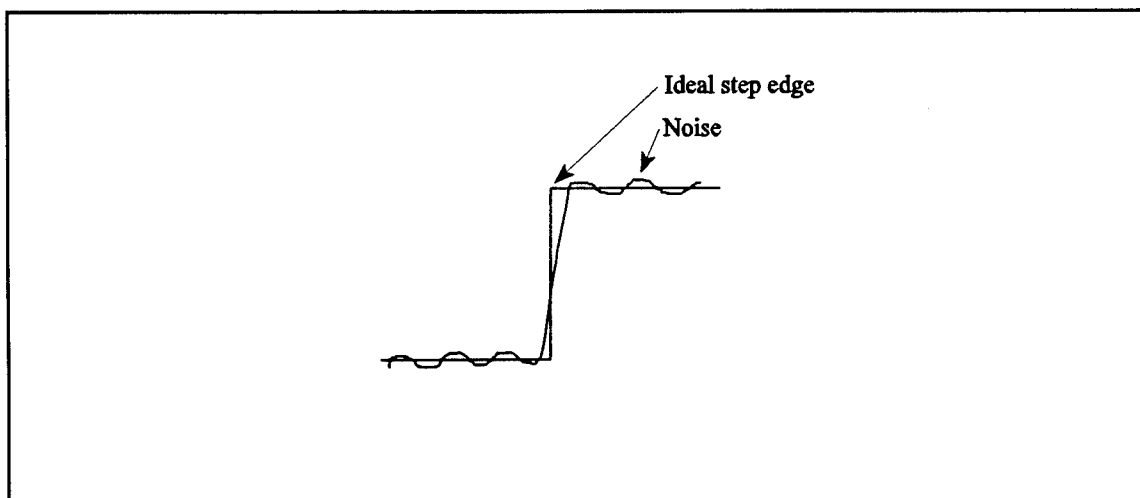
Figure 11
A one-dimensional ideal edge superimposing a real edge.

In two dimensions, the edge would occur along a line where intensity values on both sides of the line differ significantly. In order to detect the step edges in real images, the best method is to maximize the detection of desired edges and minimize the detection of undesired noise.

Consequently, researchers have discovered many edge detection spatial filters, like the Roberts, Prewitt and Sobel filters, which find most edges in images quite effectively. These spatial filters operate on a principle known as convolution.

4.2 CONVOLUTION

Convolution is defined as an operation that maps each pixel location of an input image (or source filter) to the target image, while accounting for the effects of all neighboring pixel values in the target area.[16] This is

achieved by a sequence of multiplying, adding, and then shifting operations. The source filter, or convolution mask, is usually very small compared to the target image.
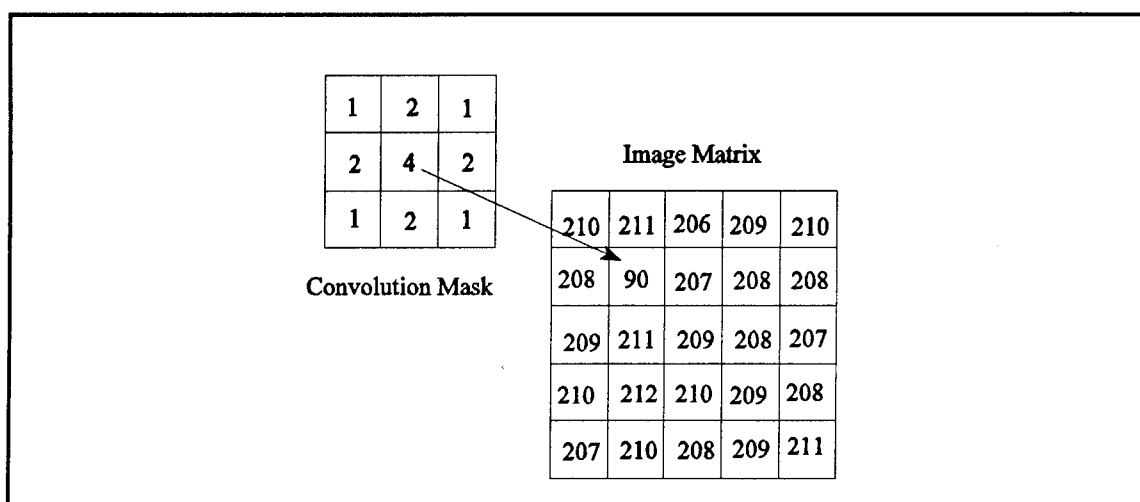
Figure 12
Applying a convolution mask on an image.

Consider a 5x5 matrix of an image section and a 3x3 convolution mask, as shown in Figure 12. Since convolution is a local or neighborhood operation, the first target pixel in the image is located at [2,2]. This allows the convolution mask to fit over that pixel in its entirety. In other words, the center pixel of the first 3x3 area of the image is assigned as the target pixel. The pixel values along the outermost boundaries of the image will remain unchanged. However, this does not pose as a problem in bullet identification, because the pixels representing the linear features of the bullet reside well within the image boundaries.

First, each pixel in the 3x3 target image area is multiplied by the corresponding value in the 3x3 convolution mask. This implies that the pixel value of the mask at [1,1] is multiplied by the pixel value of the target image at [1,1]. The process is repeated eight more times for each pixel at the different coordinate positions, until all nine pixel values of the source mask has affected the target image.

Second, all the resulting values are summed to form the new value for the center pixel in the target image area. Hence, for the first convolution operation, the new center pixel value at [2,2] will be [(210*1) + (211*2) + (206*1) + (208*1) + (90*4) + (207*1) + (209*1) + (211*2) + (209*1)]/16 = 179.

Third, the mask is shifted one position to the right to begin the cycle of multiply-add-shift, until the entire row's calculations are completed. The mask is then moved to the second value of the next row, and the process is repeated until all rows and columns of the convolution are calculated (Figure 13).

The values of the convolution mask form the type of filtering action, and are not restricted to positive values. It is also important to note that the original image is always used as the reference for computing pixel values, and

pixel values of the resultant image are not included in the computations.

210	211	206	209	210
208	179	193	208	208
209	195	202	208	207
210	210	210	209	208
207	210	208	209	211

Figure 13
Resultant image matrix.

4.3   SOBEL EDGE DETECTOR

a	b	c
d	e	f
g	h	i

Figure 14
3x3 image region.

A Sobel edge detector is a spatial filter based on a two-dimensional derivative function.[17] It detects directional transitions between two contrasting regions. Consider a 3x3 image region (Figure 14). G_x is defined as the estimate of the

derivative in the x-direction, and G_y is defined as the estimate of the derivative in the y-direction.

$$G_x = (g + 2 \times h + i) - (a + 2 \times b + c) \qquad \textbf{(2)}$$

$$G_y = (c + 2 \times f + i) - (a + 2 \times d + g) \qquad \textbf{(3)}$$

The gradient at point e (Figure 14) is

$$G = [G_y^2 + G_y^2]^{\frac{1}{2}} \qquad \textbf{(4)}$$

When the image region in Figure 14 is compared with Eq. (2), it can be seen that G_x is the difference between the first and third rows. Elements closer to e, which are b and h, are weighted twice as much as corner values. This weighting is based on intuitive grounds.[18] The same argument applies when G_y is considered.

The above equations can be implemented using Sobel operators (Figure 15). G_x is obtained by convoluting the horizontal Sobel operator on the image, and G_y is similarly obtained using the vertical Sobel operator (Eqs. 5 and 6).

$$G_x = (-1 \times a) + (-2 \times b) + (-1 \times c) + (1 \times g) + (2 \times h) + (1 \times i) \qquad \textbf{(5)}$$

$$G_y = (-1 \times a) + (1 \times c) + (-2 \times d) + (2 \times f) + (-1 \times g) + (1 \times i) \qquad \textbf{(6)}$$

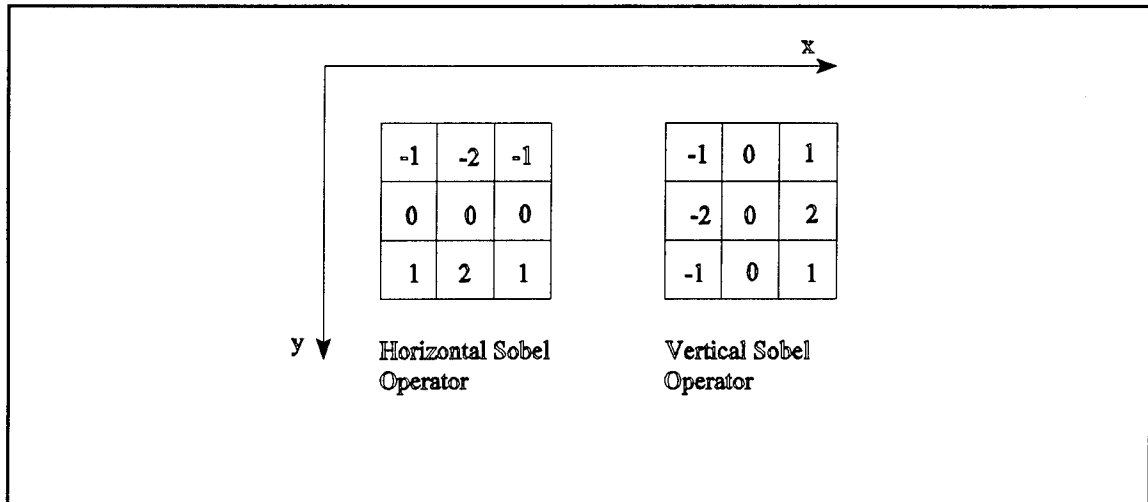The gradient G is calculated using Eq. 4.

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Figure 15
Sobel operators.

4.4   PREWITT EDGE DETECTOR
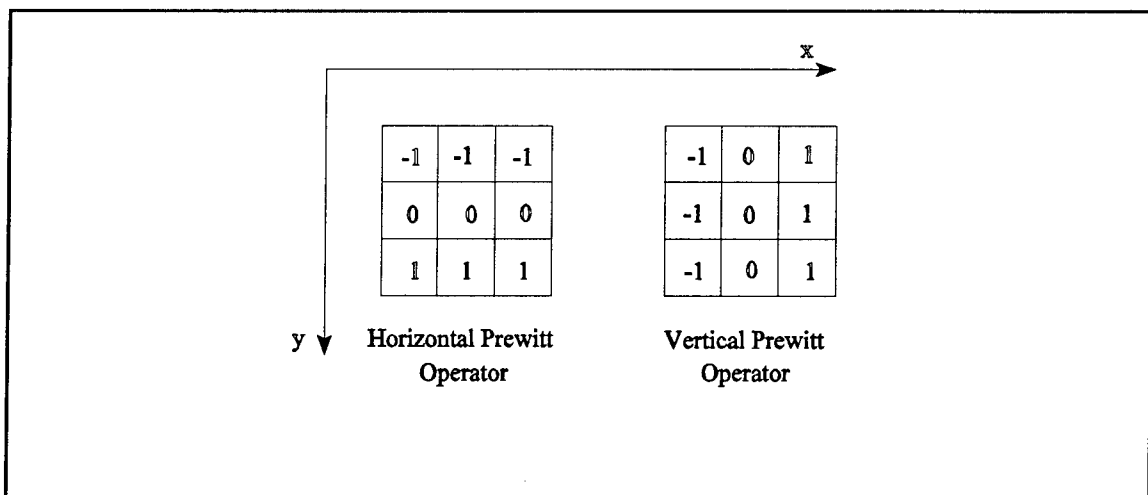
Figure 16
Prewitt operators.

Like the Sobel operators, the Prewitt edge detector is directional, and is based on a first-derivative operator. By convoluting the horizontal and vertical Prewitt operators with the image respectively, values for Gx and Gy are calculated (Eqs. 7 and 8).

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$$G_x = (-1 \times a) + (-1 \times b) + (-1 \times c) + (1 \times g) + (1 \times h) + (1 \times h) \tag{7}$$

$$G_y = (-1 \times a) + (1 \times c) + (-1 \times d) + (1 \times f) + (-1 \times g) + (1 \times i) \tag{8}$$

4.5 ROBERTS EDGE DETECTOR

Figure 17
Roberts operators.

Unlike the Sobel and Prewitt edge detectors, the Roberts edge detector consists of two operators that are 2x2 in size. The same principle applies here, when convolving the operators with the image to find G_x and G_y. However, the image section used during each convolution will only be 2x2 in size.

4.6 HOW THE BEST EDGE DETECTOR WAS DETERMINED
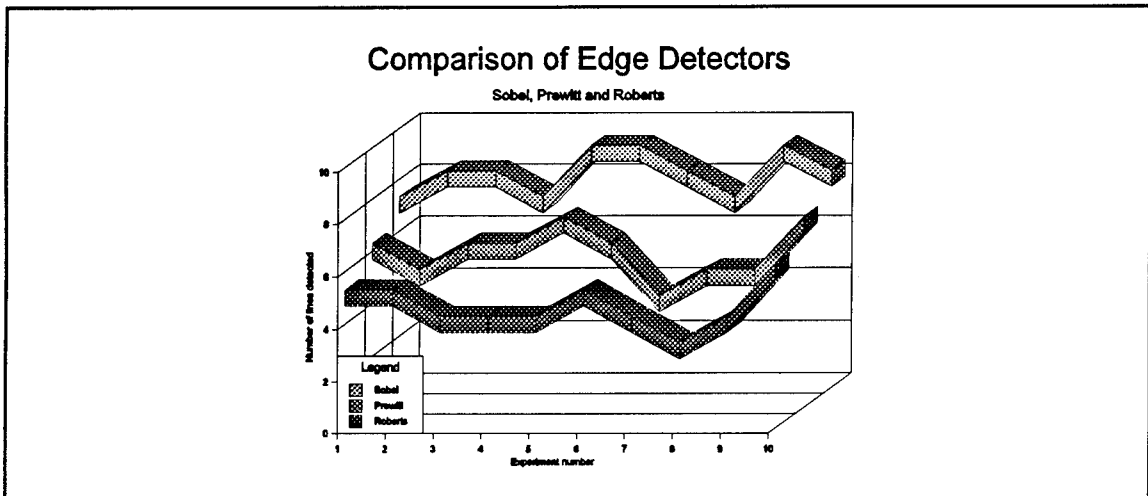
Chart 1
Comparison of Sobel, Prewitt, and Roberts edge detectors.

An experiment is created to test the response of the Sobel, Prewitt, and Roberts edge detectors. The sample used is a smooth-surfaced metal cylinder about the size of a 0.45-calibre bullet. Ten lines of various length and orientation are scratched onto the surface of the specimen, in order to simulate the rifling marks. The image of the specimen is then captured, under similar conditions as in normal bullet imaging. All three edge detectors are put to the test to see how many lines they can detect. The results of ten experiments are as shown in Chart 1. The horizontal axis indicates the experiment number, and the vertical axis indicates the number of lines detected out of the total of ten. The Sobel edge detector gives the best response.

SECTION 5 - LINEAR FEATURE EXTRACTION

There is much research done in the field of linear feature extraction[19]. It has many important civilian and military applications, such as, finding line segments in aerial images of roads, runways and maps. Here, linear feature extraction is applied to find the striations on the lands of the bullet images.
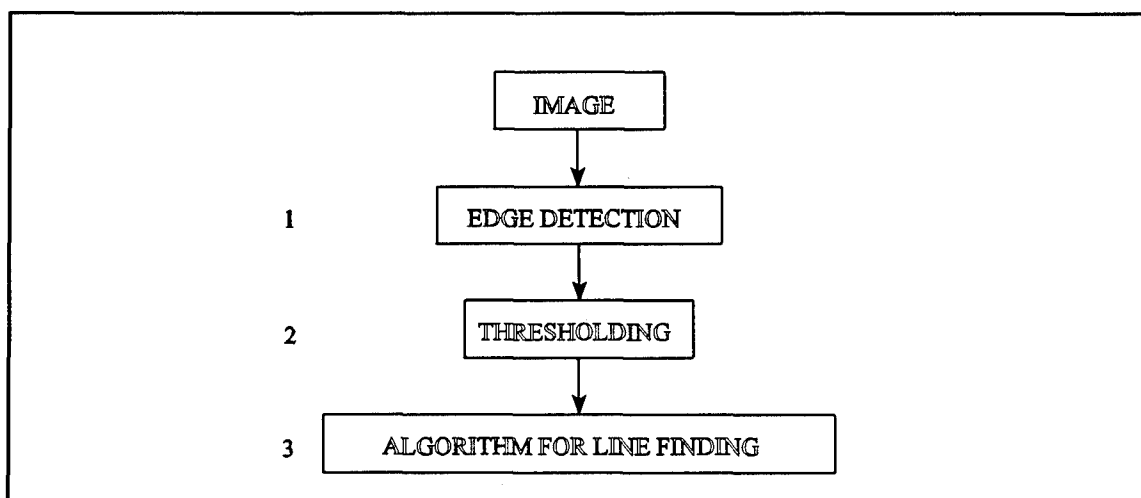
Figure 18
Three-step line finding process.

This project implements the process of line finding in three steps (Figure 18). First, edge magnitude and direction is found by convolving an image with the Sobel edge detection mask. Second, the image is thresholded to improve the line profile, and to separate the image into two grey levels (binarization). Finally, an algorithm, based on basic circle

geometry and statistical theory, is used to find the desired

lines in bullet images.

5.1   THRESHOLDING
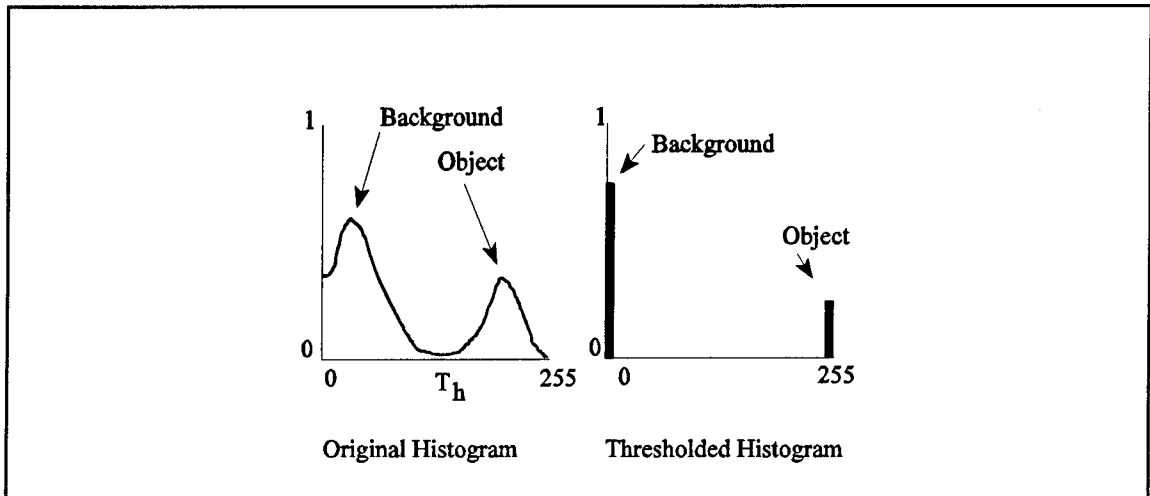
Figure 19
Comparison of histograms.

Thresholding is employed to segment the image grey level

values into particular subregions.[20] In binary thresholding

(two grey levels), a threshold value is chosen so that the

background pixels are set to 0 and the object pixels are set

to 255 (Figure 19). For example, if a threshold value T_h is

set at 190, all pixel values above 190 are set to 255 (object

- light pixels) and all pixel values at or below 190 are set

to 0 (background - dark pixels). The following equation

describes the transformation:

$$If \ f(x,y) > T_h, \ then \ g(x,y) = 255.$$
$$If \ f(x,y) \leq T_h, \ then \ g(x,y) = 0.$$

(9)

5.2   LINE FINDING ALGORITHM

The lines found in bullet images tend to be straight and
orientated at a small angle from the horizontal. This angle
corresponds to the inclination angle of the lands on the
bullet. The approach to extracting this feature is to define
a vertical line, known as the reference line, which must be
larger than the width of any particular land on the bullet.
The reference line must lie fully across the pixels of the
particular land in the image (Figure 20).
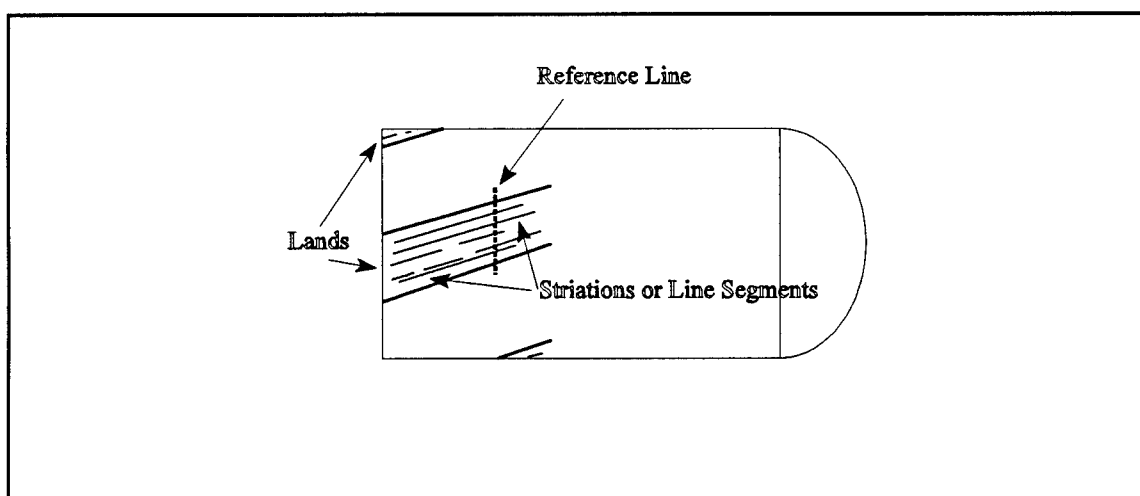
Figure 20
Line segments on lands of bullets.

The first target image pixel corresponds to the top
pixel of the reference line. Consider a pixel (c_x, c_y) to be
the center of a circle of radius r. From that pixel, a
straight line, or radius, is drawn, extending from the center
of the circle to its circumference (a,b). As the line is
rotated at an angle θ measured from the horizontal, from $-\pi/2$
to $+\pi/2$, the line would eventually travel across all pixels

of the image area within the right half of the circle (Figure 21).
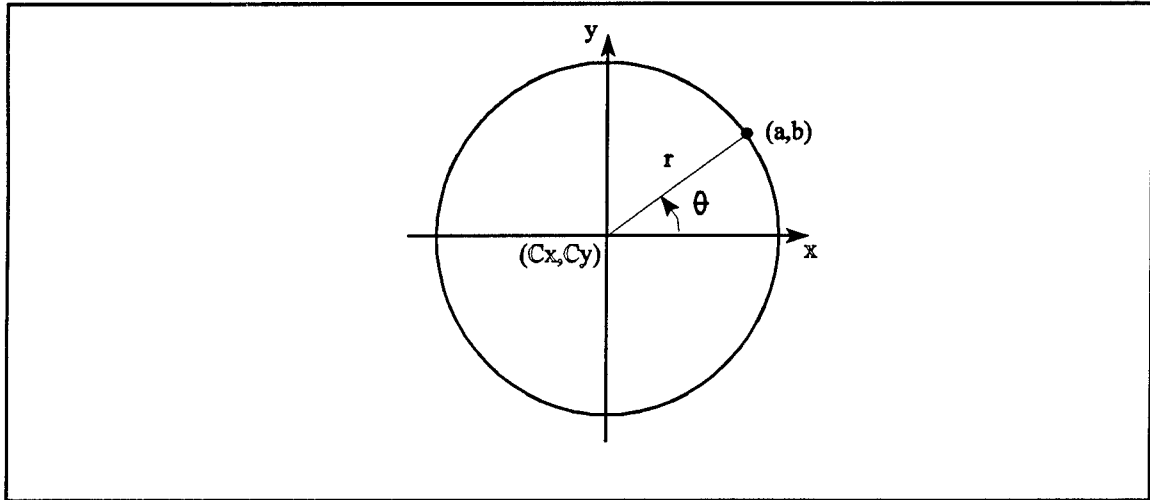
Figure 21
Representation of a circle.

The following equation defines a circle:

$$(a - c_x)^2 + (b - c_y)^2 = r^2 \tag{10}$$

Therefore, coordinates (x,y) on the straight line within the circle can be calculated from:

$$x = r \times \cos \theta$$
$$y = r \times \sin \theta \tag{11}$$

By fixing the angle θ and varying the length r, a series of coordinates representing a straight line at a particular inclination θ is obtained. Using the line coordinates and its corresponding image pixel value, statistical methods are applied to find the variance, σ^2, of the pixel values along that line. The assumption is that the pixel values on the line have a normal distribution. The variance of pixel values

is computed for angles θ from $-\pi$ to $+\pi$ at regular angular
intervals (Eqs. 12 and 13).

The mean is defined as:

$$\mu = E\{X\} = \overline{X} = \sum_{n=1}^{N} \frac{X_n}{N} \tag{12}$$

where
X_n *is the pixel grey value, and*
N *is the total number of pixels on the line.*

The variance is then defined as:

$$\sigma^2 = \sum_{n=1}^{N} \frac{(X_n - \mu)^2}{N} \tag{13}$$

The calculations are restricted on the right half of the
circle because the information in the left half is similar.
Using the calculated values, a line segment is then
considered to exist at an inclination angle θ, where the
variance of pixel values is less than a certain threshold
variance σ_{Th}^2. By experimentation, the best value for σ_{Th}^2 is
found to be 0.354. This is set as a default value in the
software program, but it allows the user to change σ_{Th}^2 if
necessary. If there exists two or more adjacent line segments
having variances within σ_{Th}^2, the one with the least variance
among them is labeled as the "real" line.

The whole process described above is repeated for the
next pixel on the reference line, until the end of the
reference line is reached. During the progress from pixel to

pixel on the reference line, the mean value, μ, and inclination, θ, are compared. If both values of μ and θ belonging to adjacent pixels do not vary from each other by 10 percent, they are assigned to the same line. The width of the line will equal to the number of adjacent pixels having same μ and θ values. If either μ or θ varies by more than 10 percent for adjacent pixels, the count for a new line begins.

As the process is cycled through the entire reference line, values for the width, inclination, and number of lines on the particular land of the bullet is recorded. These values are translated into a simple bar-code form, which is used for the identification of bullets.

5.3 BAR-CODES
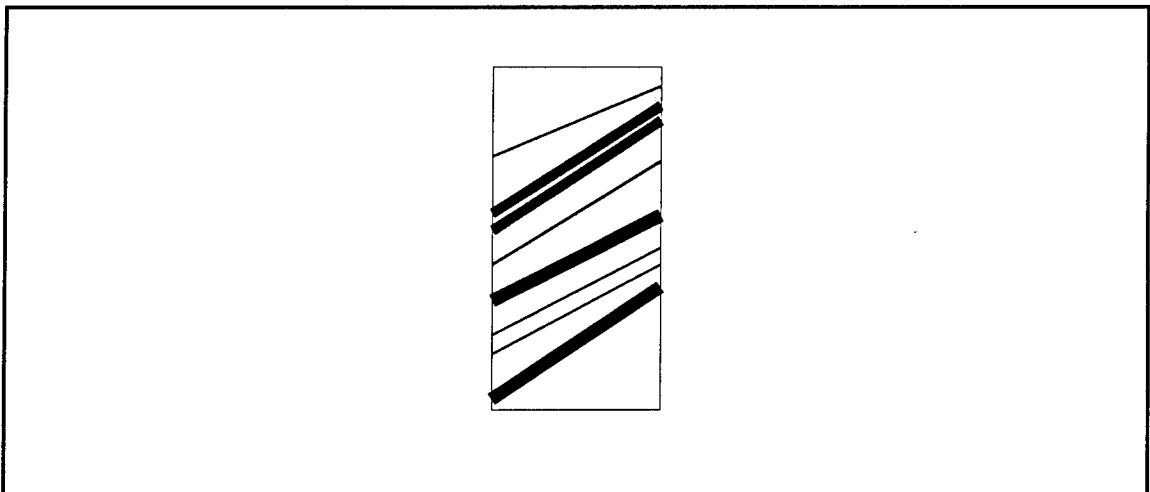
Figure 22
A typical bar-code representing the lines on a bullet.

The translation of data into bar-codes simplifies the matching process, because each bar-code contains only the

necessary data. The bar-code shows the relative position of every occurrence of a line, and it even displays the actual width and inclination of each line (See Figure 22).

It must be realized, that the bar-code is not an actual representation of the bullet image, instead, it serves only as an approximation. Important characteristic non-linear markings like stab marks and skid marks, or other distinguishing non-linear marks made by the mechanics of a particular firearm are not included in the bar-code. This is one of the reasons why the firearms expert is needed to make the final analysis and approval for the matched bullets.

A probability of match value is generated whenever two bar-codes are matched. This value tells the expert if the two bullet images are similar enough to warrant a second detailed analysis. Results of the bar-code matching process is described in Section 8. The speed and accuracy of bar-code matching greatly reduce the number of bullet images on file that the expert has to compare.

SECTION 6 - SYSTEM DESIGN

Every basic image capture and image processing system requires the following:

1. A camera to capture different intensities of reflected light from the specimen;
2. An illumination source for the specimen;
3. A frame grabber to digitize the analog signals from the camera and translate those signals into an image.
4. A computer capable of image processing calculations, data storage, and retrieval.
5. One or more display monitors to show the image and results.
6. Software to process the image for desired results.

Modern high-resolution image processing systems can cost anywhere from $10,000 to $300,000, depending on the quality and performance criteria of the hardware components. This project demonstrates that low-cost systems can also be used effectively when good software is available. It is seen as a cost-saving measure, if automated bullet identification systems were ever to be acquired on a large scale.

6.1 THE VISION SYSTEM DESIGN

The system is described beginning with a charged-coupled-device (CCD) camera mounted on a wide-field microscope (magnification x4.0) over the bullet specimen. The bullet is affixed to a bullet base attachment which is in turn, connected to the shaft of a stepper motor. The motor is

used to provide uniform rotations (200 steps per rotation)
when orientating the bullet specimen for image capture
(Figure 23).
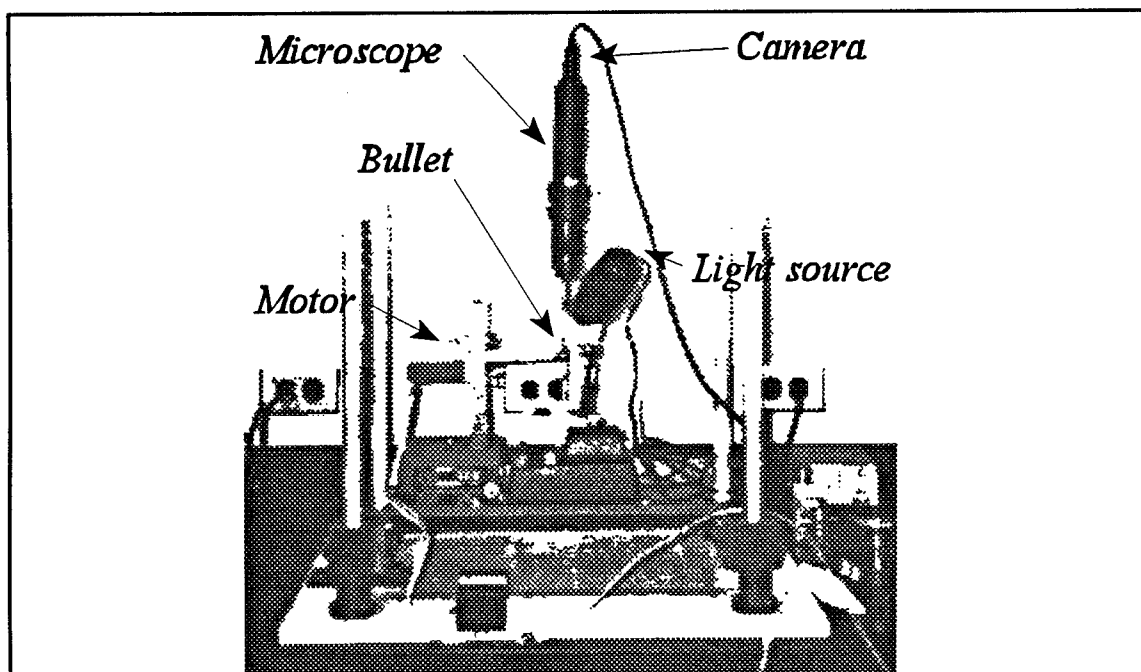
Figure 23
A picture showing hardware components of the VISION image
processing system that are responsible for the capturing of
the bullet images.

A lamp with three levels of light intensity, is used as
a simple light source for direct illumination of the bullet
specimen. However, initial experimental results indicate that
the light source causes too many specular reflections. This
creates an unacceptable level of noise in the bullet image.
A piece of translucent paper is used to diffuse the light,
providing sufficient uniform illumination for the capture of
high quality bullet images.
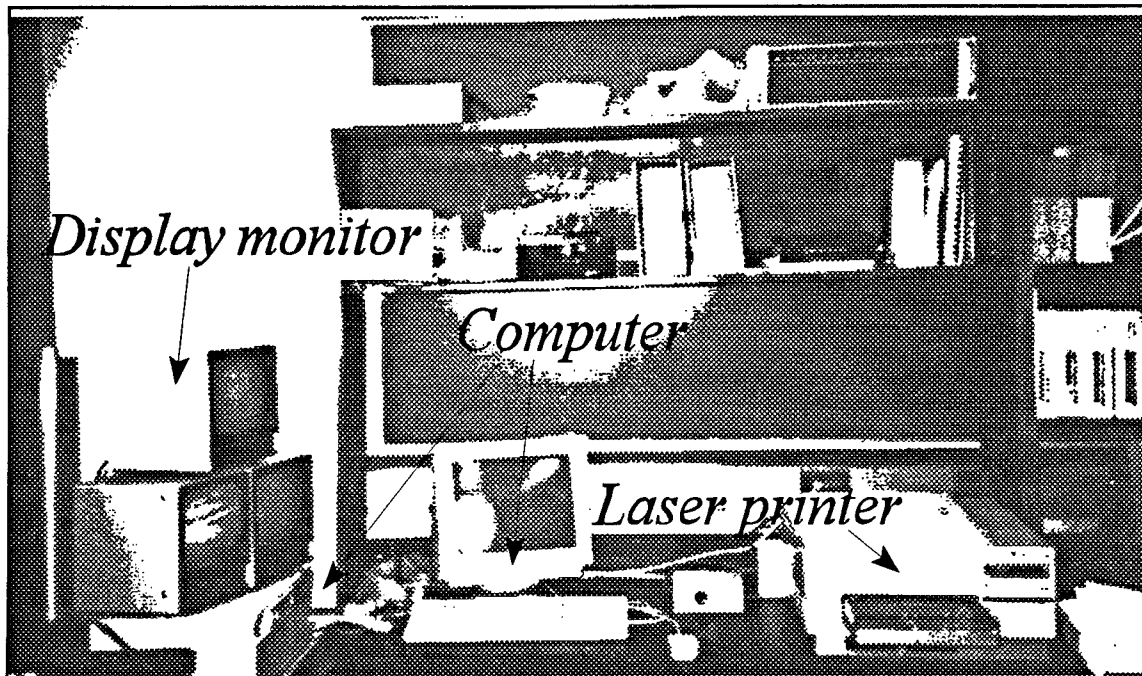
Figure 24
Picture showing other important image processing components
like the computer, display monitor and laser printer.

The frame grabber used in this project is the DT2867

Integrated Image Processor board manufactured by Data

Translation Incorporated. The analog signals from the camera

are digitized, and the discrete image produced is stored on

the frame grabber's memory. The frame processor, called the

DT2878 High Performance Image and Signal Processor Board, is

provided, but is not used in the final software product,

because the emphasis on image processing is software-driven.

The DT2878 is an array processor that specializes in computer

architecture that has been optimized for image processing

algorithms. It does not, however, perform linear feature

extraction, which is the most important goal in this project.

Hence, its use is limited to comparing the quality of image

processing between the board and the software.

Image video is displayed on a monitor via a video controller board. This enables the user to pre-select which images to capture, and make corrections for focusing and magnification prior to the actual process of image capture. The video controller also acts as a switching device that routes video data through the system.

The computer is controlled from the keyboard and mouse, and the image processing functions are processed by the computer. The computer can direct the video controller to display the image from the frame buffer to the computer screen, display monitor or the laser printer. In addition, the computer provides a means for image storage and retrieval (Figure 24). Refer to Appendix A for the VISION Image Processing System schematics and design components.

SECTION 7 - WHY USE THE MICROSOFT WINDOWS 3.1 ENVIRONMENT?

Microsoft's C/C++ is used as the programming language for the image processing software in this project. Most programmers for Microsoft Windows 3.1 feel that Windows provides a rich programming environment, supplying extensive support for the development of easy-to-use and consistent user interfaces.

Windows provides a multi-tasking graphical environment that can run several applications simultaneously. Each application displays a rectangular area on the computer screen called a window. The entire computer screen is known as the desktop, and it contains icons, menus and buttons with specific functions. Each icon represents a different application, and a particular application becomes active when the mouse is clicked over its icon. This point-and-click ease of running applications is an attractive feature, which many commercial software packages adopt.

In addition, Windows facilitates the handling of large arrays of data, which in a DOS application, would prove harder to manage. A DOS application runs in real mode, and arrays cannot exceed 64K (65535 bytes) in size. A Windows application runs in virtual mode, therefore, the arrays are not limited in size. Most importantly, the DT2867 and DT2878

image processing boards can only communicate with the Microsoft version of C/C++. This is the main reasons why Microsoft C/C++ is chosen over Borland C/C++ programming language.

SECTION 8 - EXPERIMENTAL RESULTS AND ANALYSIS

The success of the VISION Image Processing System for bullet identification is dependent on two areas - physical hardware and image processing software. The physical hardware must be able to capture and display bullet images that are of high quality and detail, while the software must be able to accomplish the goal of bullet identification.

8.1 Bullet Images

Two classes of bullets, the 0.45-calibre and 0.3-calibre, were used in this project. Experiments with the 0.3-calibre were abandoned because only two samples of the bullet were provided. The margin of error would be too great for any results to be conclusive. Moreover, the larger 0.45-calibre bullets were desirable, because they contained lines that were more distinct. This was of great help during the initial development and testing of image processing algorithms. Hence, most of the work involved the 0.45' calibre bullets. The forensics laboratory in the United States Bureau of Alcohol, Tobacco and Firearms provided all the specimen bullets for this project.

There were a total of about 250 bullet images produced by the VISION Image Processing System. Most of the early

images were discarded, because they contained too many specular reflections, or lacked the appropriate resolution.

8.2 The Final Results
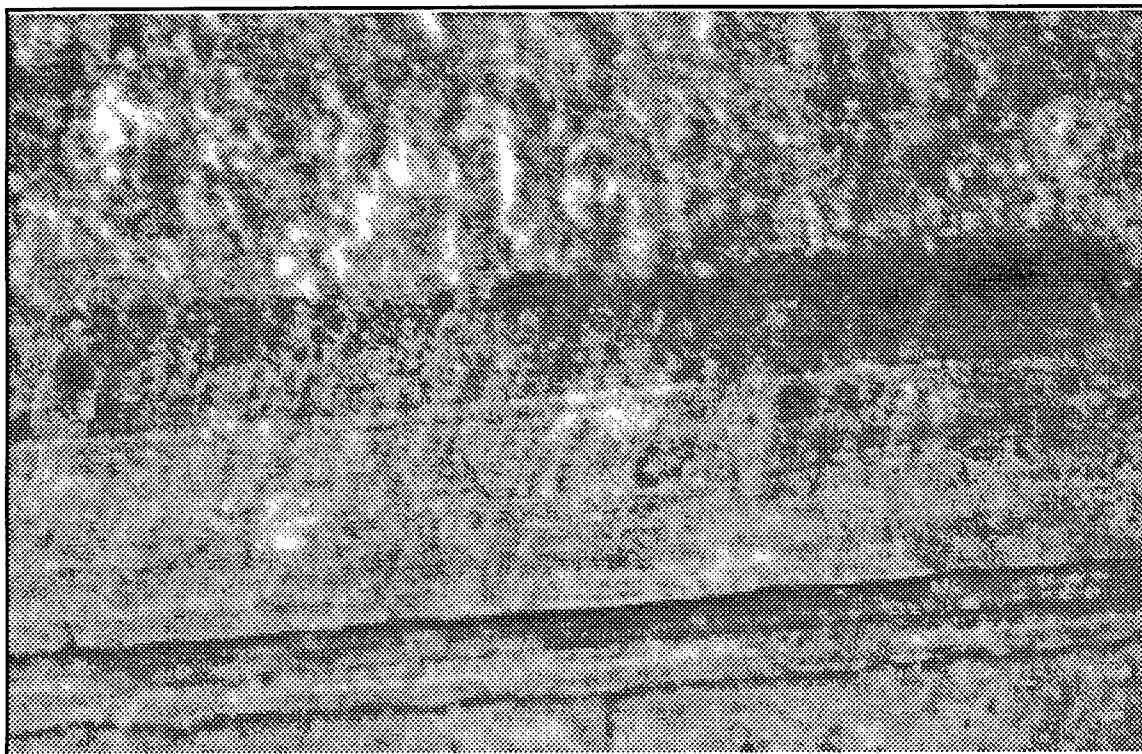
Figure 25
Original bullet image

The VISION Image Processing Software is a Windows-based application. It is user-friendly, and runs efficiently on computers with a 486 or above processor.

The image in Figure 25 is the original image of the bullet surface sample that is used for the analysis. Notice the fine striations that are found on the land of the bullet. The user can opt to sharpen or re-orientate the image, but it must be kept in mind that as more enhancement operations are

selected, the original data becomes increasingly corrupt.
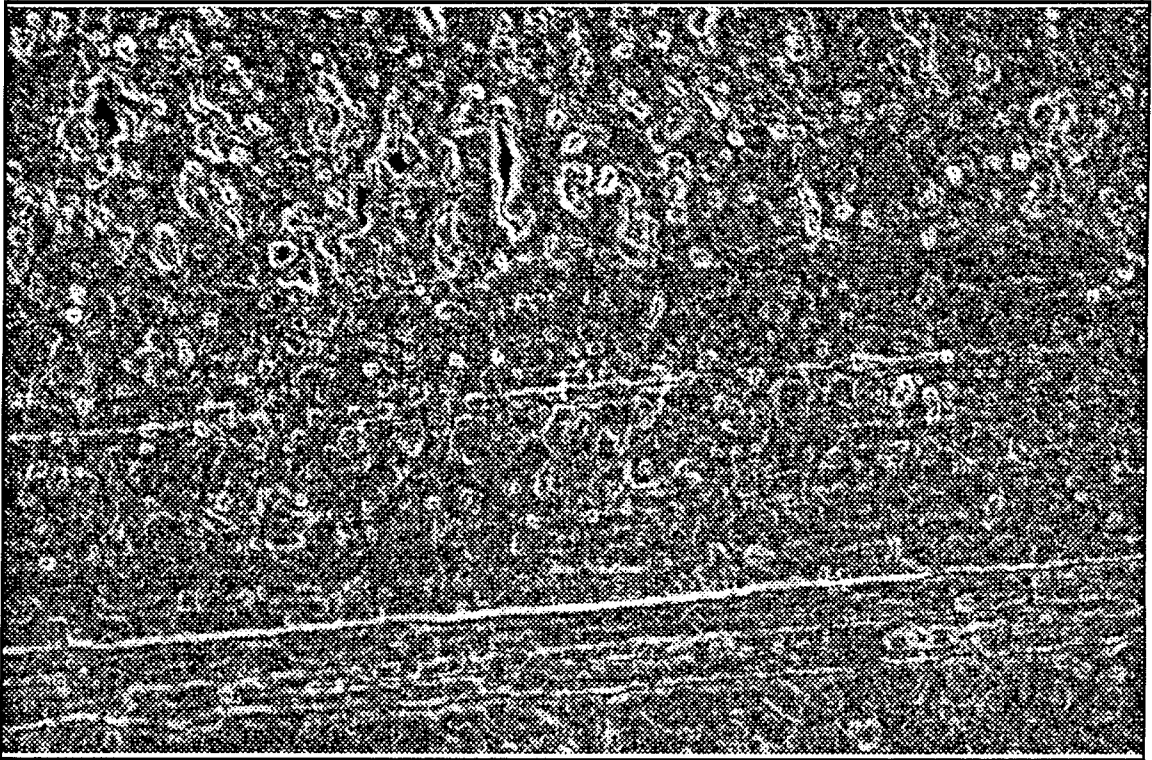
Figure 26
Image after application of Sobel filter.

First, the Sobel filter horizontal edge detector is selected. This is the most effective filter for the detection of edges in bullet images (refer to Section 4.6 for the explanation). Once the Sobel filter is selected from the menu, the computer starts applying the filter on the target area. This filtering process takes an average of 6 seconds on a 486 DX4-100 computer. The filtered image is shown in Figure 26.

Second, a threshold operation is selected to separate the filtered image into two grey levels. This is done to divide the object pixels (lines) from the background pixels

(rest of bullet surface). Refer to Figure 27 for the thresholded image.

Figure 27
Thresholded image.

Third, the user activates a negative operation, which inverts the image, changing the black pixels to white, and vice versa. This is done only to increase the visual effect of the lines by making the background white, and the line pixels black. Figure 28 shows the effect of the negative operator.

After the completion of the three image processing steps, the image is ready for linear feature extraction. A square area of size 100x100 pixels appears after the Linear Feature Extraction tool is selected, and the mouse is used to

position the square over the desired area. After an average

of 20 seconds, the computer produces the bar-code

representing the lines in the boxed area. This constitutes

the bar-code for the particular bullet image. Refer to Figure

29 for the results. This bar-code is stored with the image,

and is used, if desired, to match against other bar-codes of

different bullet images in the database.

Figure 28
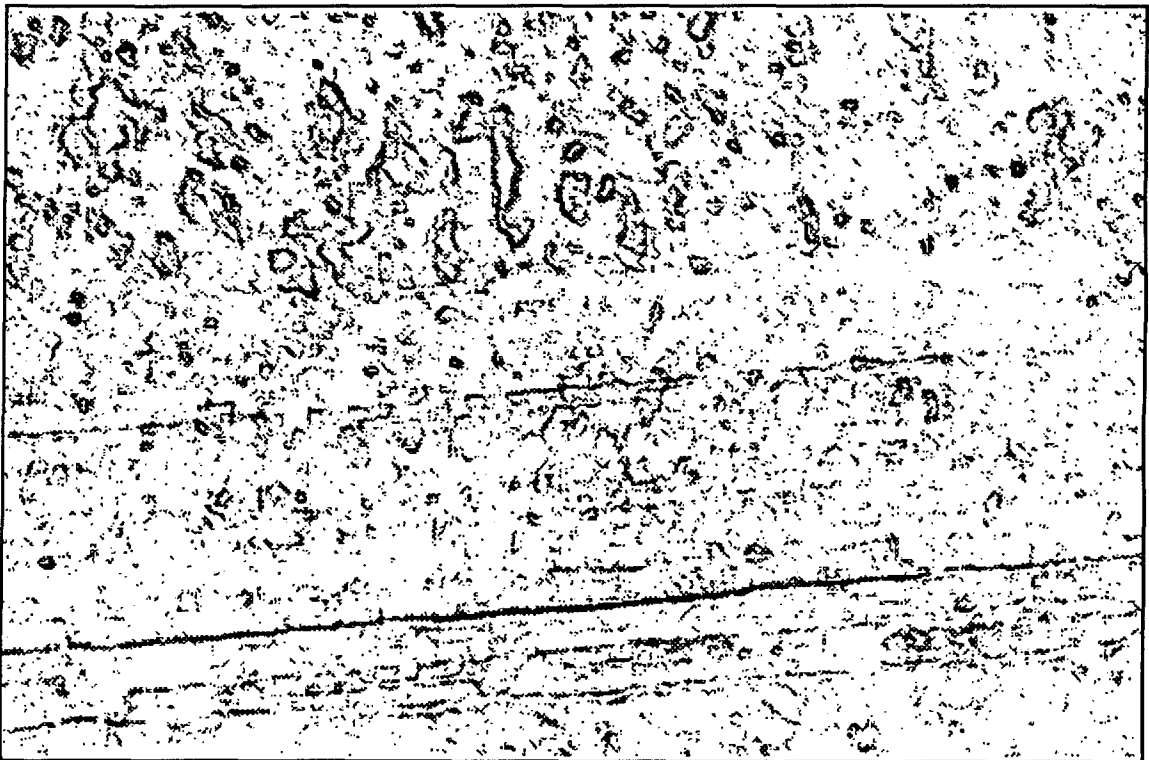Image after the application of a negative operator.

Figure 29
Bar-code of the area on the bullet surface.

Using the bar-code matching feature of the software, a decimal number is generated from 0 to 1, indicating the probability of a match. The higher number indicates that the two bullets compared are more likely to originate from the same source. See the Table 2 for the results of one of the experiments:

Bar-code Number	From Same Source?	Probability of Match
1	YES	0.754
2	YES	0.546
3	YES	0.687
4	YES	0.854
5	YES	0.985
6	NO	0.422
7	NO	0.352
8	NO	0.152

Table 2
Bar-code comparison results.

In this controlled experiment, a specimen bullet is compared with 8 different bar-codes that originate from 2 test bullets. One bullet (bar-codes 1 to 5) is fired from the same firearm as the specimen, and the other (bar-codes 6 to 8) is from another source. For every land on the bullet, a bar-code is generated for that particular land. For example, if a barrel has five separate rifling grooves, five corresponding land marks are made on the surface of the bullet. Therefore, a bar-code is made for each land, because each land can contain slight differences, even though they originate from the same barrel. Bar-codes 1 to 3 are of lands on the test bullet not corresponding to the particular land on the specimen bullet. Thus, the probability of match values are low, because of the slight differences in each land. However, bar-codes 4 and 5 are created from the land which

corresponds to the particular land of the specimen. This explains why the probability of match values are higher for bar-codes 4 and 5, compared to bar-codes 1 to 3. Hence, it also demonstrates the importance of land orientation. If land orientation is unknown for the test bullet, each bar-code associated with the test bullet must be compared with the bar-code of the specimen.

When the bar-codes of the test bullet from the other source are compared (bar-codes 6 to 8), the probability of match values, as expected, are very low. The results show that the system works, and the probability of match values are reliable. The initial success of the VISION Image Processing System can only be demonstrated by the testing of 0.45-calibre bullets. Complete tests with bullets of different sizes must be made, before the system can be applied to all bullets. However, despite this limitation, progress has been made in the field of automated bullet identification systems. The VISION image processing software is available through Assistant Professor Carl E. Wick at the Department of Weapons and Systems Engineering.

SECTION 9 - CONCLUSIONS

Overall, the objective of the project was accomplished. An image capture and image processing system was designed and constructed to obtain bullet images in two-dimensions. The image processing software VISION, was written in Microsoft C/C++ as a Windows 3.1 application. In the process of bullet image identification, it is capable of edge detection, linear feature extraction, and bar-code generation and matching. VISION's image processing techniques were based on edge detection masks, and a statistically-based algorithm for finding the width and inclination of line segments on the lands of the bullet images. Although the depth of the lands could not be calculated with this system, the software demonstrated that it was still capable of bullet identification.

This system is not intended to replace the firearms examiner, but rather, it is meant as a useful tool to increase the efficiency of firearms identification. Future improvement can be made to allow an additional analytical dimension in bullet imagery, providing land depth information. This will definitely increase the effectiveness and range of identification in the automated firearms identification system.

SECTION 10 - FUTURE ACTIVITIES

The present VISION system provides a means for two-dimensional bullet image identification. One future area of research is the use of surface mapping to provide a three-dimensional view of the bullet profile. This would facilitate the acquisition of bullet land depth data, which is an important classification descriptor in bullet identification. One possible method is to use an infrared laser and a highly sensitive infrared sensor to map surface irregularities on the rotating bullet specimen. This involves a great amount of precision and calibration of the instruments.

It is difficult to justify the costs of replacing every equipment in the system with a better one, especially on a large scale basis. A good alternative may be to procure additional equipment to supplement the existing system. For example, in this project, the DT2878 High Performance Image and Signal Processor board is not utilized, because the software is programmed to calculate all image processing algorithms. This board contains an array processor that specializes in handling complex image processing problems at great speeds. If the DT2878 board is utilized, it would free the computer's processor of image processing tasks, and allow the processor to perform other important system functions.

Hence, the overall computing time will significantly decrease.

A final improvement to the system is to make it capable of handling other areas of forensic firearms analysis. One example is the identification of bullet cartridge casings. This would greatly expand the scope of using technology to aid the firearms examiner, and hence, make a sizable contribution to the criminal justice system.

SECTION 11 - REFERENCES

1.   Sibert, Robert. "Drugfire: Responding to Gang and Drug-Related Shootings." Crime Laboratory Digest. January 1992: 6-9.

2.   Julian Hatcher, Frank Jury, and Jac Weller. Firearms Investigation Identification and Evidence. Harrisburg, PA: The Stackpole Company, 1957.

3.   Jack Gunther, and Charles Gunther. The Identification of Firearms. New York: John Wiley and Sons, Inc., 1935.

4.   Byrrard, Gerald. The Identification of Firearms and Forensic Ballistics. London: Herbert Jenkins Limited, 1934.

5.   Jack Gunther, and Charles Gunther. The Identification of Firearms. New York: John Wiley and Sons, Inc., 1935.

6.   Jack Gunther, and Charles Gunther. The Identification of Firearms. New York: John Wiley and Sons, Inc., 1935.

7.   Rafael Gonzalez and Paul Wintz. Digital Image Processing. London: Addison-Wesley Publishing Company, 1977.

8.   James Foley, Andries van Dam, Steven Feiner, and John Hughes. Computer Graphics - Principles and Practice. New York: Addision-Wesley Publishing Company, 1990.

9.   Phillips, Dwayne. Image Processing in C. Kansas: R & D Publications, Inc.,1994.

10.   Hall, Ernest. Computer Image Processing and Recognition. New York: Academic Press, 1979.

11.   Roberts, L. "Machine perception of three-dimentional solids". Optical and Electro-Optical Information Processing. Cambridge, MA: MIT Press, 1965.

12.   Prewitt, J. "Object enhancement and extraction". Picture Processing and Psychopictorics. New York: Academic Press, 1970.

13.   R. Duda, and P. Hart. Pattern Classification and Scene Analysis. New York: Wiley, 1973.

14.   Russ, John. The Image Processing Handbook. Boca Raton: CRC Press, 1992.

15. Harley Myler, and Arthur Weeks. <u>Computer Imaging Recipes in C</u>. New Jersey: P T R Prentice-Hall, 1993.

16. Nevatia, Ramakant. <u>Machine Perception</u>. New Jersey: Prentice-Hall, 1982.

17. Nevatia, Ramakant. <u>Machine Perception</u>. New Jersey: Prentice-Hall, 1982.

18. Nevatia, Ramakant. <u>Machine Perception</u>. New Jersey: Prentice-Hall, 1982.

19. Lindley, Craig. <u>Practical Image Processing in C</u>. New York: John Wiley and Sons, Inc., 1991.

20. Pratt, William. <u>Digital Image Processing</u>. New York: John Wiley and Sons, Inc., 1978.

SECTION 12 - BIBLIOGRAPHY

A. Jain, and J. Jain. "Image Restoration". IEEE Transactions on Automatic Control. October, 1978. 809-816.

Byrrard, Gerald. The Identification of Firearms and Forensic Ballistics. London: Herbert Jenkins Limited, 1934.

C. Brown, and Barry Shepherd. Graphics File Formats - Reference and Guide. Greenwich: Manning Publications Company, 1995.

D. Marr, and E. Hildreth. "Theory of Edge Detection". Proceedings of Royal Society London. Vol 207, 1980. 187-217.

Edward Dougherty, and Charles Giardina. Matrix Structured Image Processing. New Jersey: Prentice-Hall, 1987.

G. Medioni, and R. Nevatia. "Matching Images Using Linear Features". IEEE Transactions on Pattern Analysis and Machine. November , 1984. 675-685.

Hall, Ernest. Computer Image Processing and Recognition. New York: Academic Press, 1979.

Harley Myler, and Arthur Weeks. Computer Imaging Recipes in C. New Jersey: P T R Prentice-Hall, 1993.

I. Abdou, and W. Pratt. "Quantitative Design and Evaluation of Enhancement/Thresholding Edge Detectors". Proceedings of IEEE. May, 1979. 753-763.

Jack Gunther, and Charles Gunther. The Identification of Firearms. New York: John Wiley and Sons, Inc., 1935.

James Foley, Andries van Dam, Steven Feiner, and John Hughes. Computer Graphics - Principles and Practice. New York: Addision-Wesley Publishing Company, 1990.

Julian Hatcher, Frank Jury, and Jac Weller. Firearms Investigation Identification and Evidence. Harrisburg, PA: The Stackpole Company, 1957.

Levine, John. Programming for Graphics Files in C and C++. New York: John Wiley and Sons, Inc., 1994.

Lindley, Craig. Practical Image Processing in C. New York: John Wiley and Sons, Inc., 1991.

M. Bhattaacharya, and R. Agarwal. "Number Theoretic Techniques for Computation of Digital Convolution". <u>IEEE Transactions on Acoustics, Speech, and Image Processing</u>. June, 1984. 507-597.

Microsoft Corporation. <u>Windows Programmer's Reference</u>. Washington: Microsoft Press, 1990.

Microsoft Corporation. <u>Windows Guide to Programming</u>. Washington: Microsoft Press, 1990.

Nevatia, Ramakant. <u>Machine Perception</u>. New Jersey: Prentice-Hall, 1982.

Phillips, Dwayne. <u>Image Processing in C</u>. Kansas: R & D Publications, Inc.,1994.

Pratt, William. <u>Digital Image Processing</u>. New York: John Wiley and Sons, Inc., 1978.

Prewitt, J. "Object enhancement and extraction". <u>Picture Processing and Psychopictorics</u>. New York: Academic Press, 1970.

R. Duda, and P. Hart. <u>Pattern Classification and Scene Analysis</u>. New York: Wiley, 1973.

Rafael Gonzalez and Paul Wintz. <u>Digital Image Processing</u>. London: Addison-Wesley Publishing Company, 1977.

Ramakant Nevatia, and K. Babu. "Linear Feature Extraction and Description". <u>Computer Graphics and Image Processing</u>. Vol 13, 1980. 257-269.

Rector, Brent. <u>Developing Windows 3.1 Applications with Microsoft C/C++</u>. Indiana: SAMS Publishing, 1992.

Roberts, L. "Machine perception of three-dimentional solids". <u>Optical and Electro-Optical Information Processing</u>. Cambridge, MA: MIT Press, 1965.

Russ, John. <u>The Image Processing Handbook</u>. Boca Raton: CRC Press, 1992.

Sibert, Robert. "Drugfire: Responding to Gang and Drug-Related Shootings." <u>Crime Laboratory Digest</u>. January 1992: 6-9.

Tim Farrell, and Runnoe Connally. <u>Programming in Windows 3.1, Second Edition</u>. Indiana: QUE Corporation, 1992.

Winograd, S. "On Computing the Discrete Fourier Transform". <u>Mathematics of Computation</u>. January, 1978. 175-199.

APPENDIX A — VISION IMAGE PROCESSING SYSTEM SCHEMATICS AND DESIGN COMPONENTS